

## **NOTICE CONCERNING COPYRIGHT RESTRICTIONS**

This document may contain copyrighted materials. These materials have been made available for use in research, teaching, and private study, but may not be used for any commercial purpose. Users may not otherwise copy, reproduce, retransmit, distribute, publish, commercially exploit or otherwise transfer any material.

The copyright law of the United States (Title 17, United States Code) governs the making of photocopies or other reproductions of copyrighted material.

Under certain conditions specified in the law, libraries and archives are authorized to furnish a photocopy or other reproduction. One of these specific conditions is that the photocopy or reproduction is not to be "used for any purpose other than private study, scholarship, or research." If a user makes a request for, or later uses, a photocopy or reproduction for purposes in excess of "fair use," that user may be liable for copyright infringement.

This institution reserves the right to refuse to accept a copying order if, in its judgment, fulfillment of the order would involve violation of copyright law.

A REEVALUATION OF GEOTHERMAL POTENTIAL OF THE WILBUR HOT SPRINGS AREA, CALIFORNIA

J. M. Thompson

U.S. Geological Survey  
Menlo Park, CA 94025

ABSTRACT

In a recent assessment of the geothermal potential of the Wilbur Mining District, it was estimated that a thermal brine at about 150°C is present at depths less than 3 km. The Na-K-Ca geothermometer applied to the four major spring groups in this area gives temperatures ranging from 220 to 240°C. The magnesium corrected geothermometer gives inconsistent temperatures suggesting that Mg enters the water during its passage from the reservoir to the surface. For this reason the Mg correction is not considered appropriate and the fluids are estimated to have originated at 230°C. From the CH<sub>4</sub>, H<sub>2</sub>S, and CO<sub>2</sub> concentrations in the spring gases at Wilbur Hot Springs and from equations devised primarily for use in steam wells, reservoir temperatures from 227° to 242°C are calculated.

INTRODUCTION

White (1957) suggested that connate water underlies the Wilbur Mining District and that this water is affected by low-grade metamorphism of

deep rocks. This could give rise to the peculiar thermal water composition of the four active springs in the Wilbur Mining District: Wilbur Hot Spring, Jones' Fountain of Life, Blanck's Spring, and the Elgin Mine springs. All but the Elgin Mine springs issue from the topographic low (see Fig. 1) of Sulphur Creek. J. M. Donnelly (oral communication, 1979) has mapped a dike of 1.6-m.y. andesitic basalt in the vicinity of Wilbur Hot Springs. This andesitic basalt is undoubtedly too old to be the present day heat source for the springs in the Wilbur Mining District, but it may indicate that magma or hot rock is still present under the Wilbur Mining District.

GEOOTHERMOMETRY COMPARISONS

In 1968 a geothermal well, Wilbur #1, was drilled to a depth of 1300 m approximately 1 km southwest of Wilbur Hot Springs, outside of the major thermal activity. White and others (1973) reported that this well erupted water at 140°C. A chemical analysis by Sunoco Energy Development Company of the well water (Table 1) reported 14,400 mg/L Cl, 1500 mg/L higher than that reported in White and others (1973). Compared

Figure 1 Generalized map of the Wilbur Mining District, Calif.

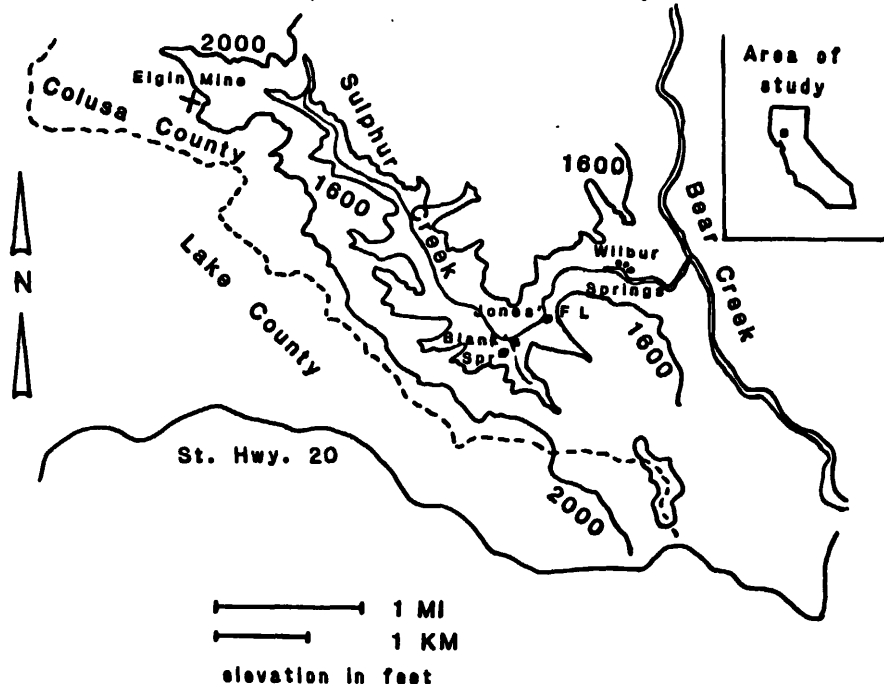


Table 1. Averaged concentrations for spring and well water in the Wilbur mining district<sup>1</sup>

	Wilbur Hot Spring	Jones' Fountain of Life	Blanck's Spring	Elgin Mine Springs	Wilbur #1 Geothermal well	Meteoric water
T °C	52	60	42	61	140	19.5
pH	7.5	7.7	7.8		8.8	6.8
SiO <sub>2</sub>	176	89	124	198	133	21
Al	1.8	---	---	---	---	---
Fe	0.17	0.35	0.19	0.17	---	---
Mn	0.04	0.05	0.05	1.0	---	---
Ca	2.5	2.6	3.5	4.8	1	3.4
Mg	45	31	69	28	2	182
Sr	3.6	1.6	1.4	3.7	---	---
Ba	3.1	3.0	1.5	---	---	---
Na	8700	9880	7220	9330	10,000	132
K	408	432	360	540	440	4.1
Li	11.6	10.7	6.9	11	---	0.16
NH <sub>4</sub>	294	120	125	243	275	---
HCO <sub>3</sub>	6900	5740	6390	7270	5170	1020
CO <sub>3</sub>	---	---	---	---	1170	0
SO <sub>4</sub>	356(4)	71	180	86	263	185
Cl	9980	11,700	8050	11,550	14,400	83
F	2.4	3.5	2.3	3.2	16	.37
Br	19	34	24	30	---	---
I	12	23	18	25	---	---
B	233	240	150	240	---	---
H <sub>2</sub> S	165	---	---	170	148	---
Na-K-Ca	236	232	232	244	244	---
Mg corr Na-K-Ca	84	118	46	148	243	---
SiO <sub>2</sub> Adiabatic	218	---	198	208	---	---
Conductive	---	223	---	---	201	---

<sup>1</sup>Analyses in mg/L

to Wilbur Hot Springs (see Table 1) Wilbur #1 geothermal well contains (1) a higher chloride content (14,400 vs. 10,000 mg/L), (2) a lower sulfate content (260 vs. 360 mg/L) and (3) a much lower magnesium content (2 vs. 45 mg/L).

The magnesium corrected Na-K-Ca geothermometer (Fournier and Potter, 1978) indicates temperatures ranging from 40 to 160°C. However, because the country rock around Wilbur Hot Springs is principally serpentinite, the high magnesium in Wilbur Hot Spring is probably due to serpentine dissolution. The uncorrected Na-K-Ca (Fournier and Truesdell, 1973) temperatures, which range from 220 to 248°C, may be more reasonable. Water from Wilbur # 1 geothermal well has a Na-K-Ca temperature of 244°C (Table 1) and very little magnesium; a correction of only 1°C is calculated.

Due to possible silica addition from serpentine dissolution, severe difficulties are encountered when using dissolved silica

concentration in estimating thermal reservoir temperatures. The difficulties include the following: (1) the silica may have already polymerized or precipitated so that direct application of the silica geothermometer (Fournier and Rowe, 1966) will indicate a low reservoir temperature; (2) the thermal water is probably mixed with dilute meteoric water giving rise to the observed spring water compositions and temperatures; and (3) the diluting water or the warm mixed water may contain some silica originating from low-temperature serpentine dissolution. For comparison, the conductive and adiabatic (with assumed subsurface steam loss at 100°C) silica-mixing-model temperatures (Truesdell and Fournier, 1977) of the warm springs are shown in Table 1. Despite all of the possible problems using silica concentrations in springs from this area, the adiabatic mixed-water temperatures are in moderate to good agreement with the Na-K-Ca temperatures. Fournier (1979) indicated that silica reequilibration is more likely to occur than Na-K-Ca reequilibration. The

silica concentration in a water sample from Wilbur #1 geothermal well is below that expected in a 220° to 240°C water; however, it may be in approximate equilibrium with quartz at 150°C or chalcedony at 130°C (Truesdell, 1976). The quartz equilibrium temperatures at 150°C and the Na-K-Ca equilibrium temperatures at 230°C in Wilbur #1 are inferred to represent high initial water temperature (230°C) and slow rate of water movement. Ultimately, little confidence can be placed in the temperatures estimated from the dissolved silica concentrations of the springs because of the numerous possible complications.

In an attempt to calculate a third independent reservoir temperature, gas samples were collected and analyzed. Franco D'Amore and A. H. Truesdell (written communication, 1979) have devised a system of equations for geothermal steam wells which quantitatively relate the concentrations of CH<sub>4</sub> and CO<sub>2</sub> and of H<sub>2</sub>S and CO<sub>2</sub> measured at the surface to the temperature in the producing zone. Using their equations the reservoir temperatures in Table 2 were calculated for Wilbur Hot Springs. These temperatures are in excellent agreement with the uncorrected Na-K-Ca temperatures from the spring waters.

Table 2.--Gas Analyses of Wilbur Hot Springs<sup>1</sup>

Date Collector	Wilbur Hot Springs		
	12-11-77 AHT	12-11-77 AHT	8-16-78 JMT
CO <sub>2</sub>	54.2	69.3	76.7
H <sub>2</sub> S	2.66	2.94	2.92
NH <sub>3</sub>	0.622	0.00	0.0323
H <sub>2</sub>	9.36x10 <sup>-4</sup>	2.66x10 <sup>-3</sup>	1.08x10
Ar	0.319	0.217	0.188
O <sub>2</sub>	4.71	1.26	0.635
N <sub>2</sub>	29.0	18.8	15.1
CH <sub>4</sub>	2.36	3.33	3.28
C <sub>2</sub> H <sub>6</sub>	0.00	0.00	0.00
TOTAL	93.87	95.85	98.22
T	242°C	237°C	227°C

<sup>1</sup>Analyses in mole percent. Analyses by Nancy L. Nehring, U.S. Geological Survey.

The Wilbur Hot Springs water composition may result if one part diluting water such as that in Table 1 mixes with two or three parts of thermal water such as that from the Wilbur #1 geothermal well. This diluting water may be unusual because it contains a high magnesium content from dissolved serpentine. Alternatively, the magnesium from serpentine dissolution may not enter the system until after mixing. Another possible scheme is that 230°C water mixes with connate water similar to that described by White and others (1973) to form the ~150°C water in

Wilbur #1 geothermal well. This water then mixes with cold meteoric water in different proportions producing the various spring water compositions. This model is not favored because it requires three different water types. Presently, the time at which the magnesium enters the system cannot be determined. The additional sulfate (115 mg/L) probably arises from oxidation of H<sub>2</sub>S in the near surface region.

#### CONCLUSIONS

The brine in the Wilbur #1 geothermal well result from the mixing of deep thermal water of unknown composition at a temperature near 230°C and connate water such as that described by White and others (1973). Alternatively, the connate water may have been heated to near 230°C and then mixed with meteoric water in proportions of 2:1 or 3:1. This diluting meteoric water may contain as much as 180 mg/L Mg. This mixed water may then slowly rise to the surface without appreciable residence in a large reservoir where Na-K-Ca reequilibration could occur. The depth to the 230°C water is unknown.

#### REFERENCES

- Fournier, R. O., 1979, Geochemical and hydrologic considerations and the use of enthalpy-chloride diagrams in the prediction of underground conditions in hot-spring systems: *Journal of Volcanology and Geothermal Research*, v. 5, - 1-16.
- Fournier, R. O., and Potter, R. W., II, 1978, A magnesium correction for the Na-K-Ca chemical geothermometer: U.S. Geological Survey Open-File Report 78-986, 24 p.
- Fournier, R. O., and Rowe, J. J., 1966, Estimation of underground temperatures from the silica content of water from hot springs and wet-steam wells: *American Journal Science* 264, p. 685-697.
- Fournier, R. O., and Truesdell, A. H., 1973, An empirical Na-K-Ca geothermometer for natural water: *Geochimica et Cosmochimica Acta*, 37, p. 1255-1275.
- Truesdell, 1976, Summary of Section III Geochemical and Geophysical Techniques in Exploration: *Proceedings 2nd U. N. Symposium on the Development and use of Geothermal Resources*, San Francisco, 19875, v. 1 p lxxiii.
- Truesdell, A. H., and Fournier, R. O., 1977, Procedure for estimating the temperature of hot-water component in a Mexico water by using a plot of dissolved silica versus enthalpy: *Journal Research U.S. Geological Survey*, v. 5, p. 49-52.
- White, D. E., 1957, Magmatic, connate, and metamorphic waters: *Geological Society of America Bulletin*, v. 68(12) pt. 1, p. 1659-1682.
- White, D. E., Barnes, Ivan, and O'Neil, J. R., 1973, Thermal and mineral waters of non-meteoric origin, California Coast Ranges: *Geological Society of America Bulletin* v. 84, p. 547-560.